SUMMARY REPORT

Classification Demonstration at the former Spencer Artillery Range, TN Open Area

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1. Introduction

Classification using the MetalMapper advanced electromagnetic sensor was demonstrated at the former Spencer Artillery Range, TN in 2012. Three parallel demonstrations were conducted at this site. This report summarizes the results of the MetalMapper demonstration in the "Open Area." Later reports will document the results of the demonstrations in the "Dynamic" and "Wooded" areas. The document *Implementing Classification on Munitions Response Sites* (Ref. 1) provides practical information for deciding whether classification is appropriate to a particular site and how it is best implemented.

Spencer Artillery Range, TN, Open Area –a variety of projectiles expected, flat terrain with open access, minimal geologic interference, medium anomaly density

Munitions – 37-mm, 75-mm, 76-mm, 105-mm and 155-mm projectiles

Results –Production contractor field crews from two different vendors collected cued MetalMapper data. Both production contractor geophysicists and the developers of classification methods were successful in using these data to achieve substantial classification. Most analysts correctly identified all, or all but one, TOI while correctly classifying 75 to 90% of the clutter. The best predictor of classification performance was analyst experience which emphasizes the importance of continued training.

Classification is motivated by the need to perform munitions response more cost-effectively so that limited clean up dollars can be used to reduce real risk on munitions-contaminated sites sooner. The estimated liability in the FY10 Defense Environmental Programs Report to Congress for Munitions Response is $15.2B. (Ref. 2) The bulk of this liability is $10.0B for the 1703 sites identified in the Formerly Used Defense Sites (FUDS) program and $4.4B for the 2433 sites identified on Active Installations. The remaining $0.8B is in Base Realignment and Closure (BRAC). The estimated completion dates for many sites, particularly in the FUDS program, are decades out if they are to be cleaned up at planned funding levels using current practice.

When a munitions response site is cleaned up, in most cases, it is mapped with a geophysical sensor and the locations of all detectable signals are excavated. Geophysical sensors detect metal and, therefore, many of the detections do not correspond to munitions, but rather to harmless metallic objects. Field experience indicates that 95-99% or more of objects are found to be nonhazardous. Currently-used technology does not provide a means to discriminate between munitions and other items, termed "clutter." As a result, most of the costs to remediate a munitions-contaminated site using current methods are spent on excavating targets that pose no threat.

Classification is a process used to make a decision about the likely origin of a signal. In the case of munitions response, high-quality geophysical data can be interpreted with physics-based models to estimate parameters that are related to the physical attributes of the object that resulted in the signal, such as its physical size and aspect ratio. The values of these parameters may then be used to determine whether the signal arose from a munition or harmless clutter. With reliable classification, only the munitions need to be removed from the site.

The Strategic Environmental Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP) have supported the development of purpose-built advanced electromagnetic sensors and associated analysis methods for classification. Following the successful demonstration of classification methods in controlled test environments, ESTCP initiated a Classification Pilot Program to validate the application in real-world conditions. The goal of the program is to demonstrate that classification decisions can be made using an explicit approach, based on principled analysis that is transparent and reproducible. The demonstrations are planned and conducted in cooperation with regulators and program managers in the Services.

The physics governing the electromagnetic response of a metal object is well understood and predictable. Data collected with these sensors contain the same information content on any site and demonstrations to date have confirmed that classification works predictably. Nevertheless, demonstrations will be required at a number of sites to represent the wide variability in munitions types, target densities, terrain, vegetation, geology, land use history, future land use, and other site characteristics that will affect the applicability of classification and to establish cost effectiveness and implementability. The demonstrations also present an opportunity to work out standard operating procedures and establish quality control (QC) measures. Prior demonstrations have been conducted at a number of sites across the country; details about past and ongoing demonstrations can be found on the SERDP-ESTCP web site at http://serdp-estcp.org/Featured-Initiatives/Munitions-Response-Initiatives/Classification-Applied-to-Munitions-Response.

The demonstration at Spencer Artillery Range continues the practice of data collection by production contractors and data analysis by both production geophysicists and the developers of the analysis methods. This is an important consideration in evaluating and applying the results; the production geophysicists are far less experienced than the developers and any performance shortcomings should be attributed to inexperience. Table 1 shows the participants and their roles in the Spencer demonstration.

Table 1. Participants in the MetalMapper Demonstration at former Spencer Artillery Range

<table>
<tr><th>Task</th><th>Performer(s)</th><th>Task</th><th>Performer(s)</th></tr>
<tr><td>Site Preparation</td><td>URS, Corp.</td><td rowspan="2">Data Analysis</td><td rowspan="2">Dartmouth College
NAEVA
SAIC
Shaw
SIG, Inc.
Sky Research, Vancouver*
URS, Corp
USACE</td></tr>
<tr><td>MetalMapper Data Collection</td><td>URS, Corp
NAEVA</td></tr>
<tr><td>Intrusive Investigation</td><td>URS Corp</td><td>Scoring</td><td>Institute for Defense Analyses</td></tr>
</table>

2. Spencer Demonstration Flow

The sequence of the demonstration is outlined in the flow chart in Figure 2-1.

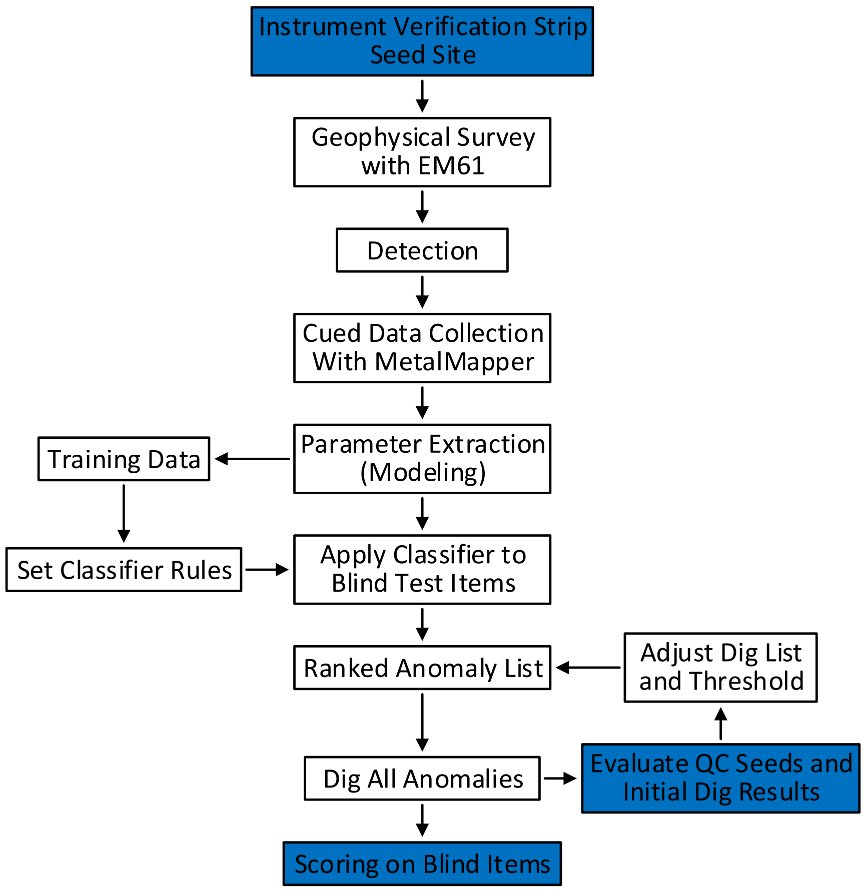

Figure 2-1. Flow chart outlining steps in the demonstration at Spencer Artillery Range. Blue boxes are tasks performed by ESTCP. Others are tasks performed by contractors.

Prior to the beginning of data collection, an instrument verification strip (IVS) was installed and the site was seeded with inert munitions and small (1-in nominal x 4-in Schedule 80 pipe nipples) and medium (2-in nominal x 8-in Schedule 40 pipe nipples) industry standard objects (ISOs). (Ref. 3) The data collection teams visited the IVS twice daily to verify equipment function at the start and end of each day. Since there are few native unexploded ordnance (UXO) on any munitions response site, the seeds provided sufficient targets of interest (TOI) to allow a statistically defensible determination of the correct classification of TOI.

Targets of Interest (TOI) are all objects that must be removed from the site. Typically the TOI will include all known or suspected munitions types, any other unexpected munitions, munitions parts such as fuzes that present an explosive hazard, and all seeded items. When classification is applied to a site, the local project team will decide what items constitute TOI.

The site was surveyed with an EM61 to provide an initial list of detected anomalies. The MetalMapper was used to collect cued data over each anomaly. All detected targets were dug up to provide complete ground truth for the purposes of determining performance. The UXO technicians photographed each item that was dug and recorded its location, depth, and description.

The cued geophysical data were passed to the data analysis teams. A complete overview of the analysis procedures can be found in Ref 1. Briefly, the analysts used methods based on the dipole model to estimate target parameters. Analysts were offered training data from test pit measurements and the opportunity to request additional training data from the recovered targets, as though they were doing a limited number of sample digs. These data were used to set classifier rules – the decisions that separate the anomalies into TOI and non-TOI. The classifiers were then applied to all of the targets that remained blind for each demonstrator. Since training data was by request, the blind target set was different for each demonstration.

The product required from each analyst was a ranked anomaly list; an example is shown in Figure 2-2. One and only one judgment is required for each entry on the anomaly list. The first items below the training data on each anomaly list are those targets for which reliable parameters cannot be extracted and therefore must be dug. Next are those items which the analyst is the most confident are TOI. These items are ranked according to decreasing likelihood that the item is a TOI. Any items which the analyst was able to analyze but was not able to make a classification decision on at this time were placed next on the anomaly list. Last are all those items that the analyst was confident are not TOI ranked by their likelihood. The analysts were required to specify a size estimate for any item marked to be dug. This initial list is shown in the left panel of Figure 2-2.

Initial Ranked Anomaly List

Anomaly ID	Dig on First Pass	Type	Comment
718	Y		Classifier training data
207	Y		
2498	Y		Unable to extract reliable parameters
247	Y	105 mm	
1114	Y	4.2 in	High likelihood TOI
69	Y	155 mm	
811	Y	81 mm	
First Pass Threshold			
313	N		Unable to classify
883	N		
...	N		
...	N		
...	N		High likelihood not TOI
...	N		
...	N		
...	N		
...	N		
...	N		
...	N		

Final Ranked Anomaly List

Anomaly ID	Dig	Type
718	Y	
207	Y	
2498	Y	
247	Y	105 mm
1114	Y	4.2 in
69	Y	155 mm
811	Y	81 mm
313	Y	105 mm
Final Threshold		
883	N	
...	N	
...	N	
...	N	
...	N	
...	N	
...	N	
...	N	
...	N	
...	N	

Figure 2-2. Example initial and final Ranked Anomaly Lists. A detailed description is in the text.

The seeds were divided into QC seeds and blind seeds. When analysts submitted their initial prioritized lists, the QC seeds were used to provide feedback if seed targets were missed. Analysts were also provided with the ground truth information on all anomalies in the red part of their lists and any requested anomalies in the yellow part. This is signified by the threshold on the left list in Figure 2-2. Based on this information, the analysts were then allowed to revisit their rankings and assignments for all items that were still blind until they were satisfied that the best possible classification had been achieved.

In the final list, shown in the right panel of Figure 2-2, the analyst is required to provide a threshold that corresponds to the division between those items recommend for digging and those that can safely remain in the ground. That is, every item on the list is marked to be dug or not with a threshold separating the two categories. The final prioritized anomaly lists submitted in this demonstration were scored against the emplaced blind seeds and recovered targets by IDA.

3. Site Description and Preparation

The former Spencer Artillery Range is a 30,618 acre site located near Spencer, Tennessee. (Ref. 5) Construction of the range began in 1941 and documentation identifies establishment of two impact areas: Jakes Mountain (5,060 acres) and Bald Knob (2,090 acres). Troop training took place until September 1944, by which time Army ground forces had either departed or were under orders to depart. Subsequent arrangements were made for Dyersburg Army Air Field to use the Spencer Artillery Range as an air-to-ground gunnery range. The land reverted back to the original 25 leaseholders in the summer of 1946. Several surface decontamination sweeps were completed on portions of the former range in the 1950s. Since then, numerous tracts of land have been sold and/or subdivided, significantly increasing the number of property owners from the original 25 to several hundred landowners today.

The demonstration was conducted in a portion of Munitions Response Site (MRS) 1. An aerial photo of the site is shown in Figure 3-1 with the three parallel demonstration areas marked.

All visible metal objects were removed from the surface at the site. First order reference points were installed by a registered surveyor for geolocation reference. An area free of contamination was located near the demonstration area to establish an IVS used for daily verification of proper sensor operation and a training pit to collect sensor data for algorithm training.

The known munitions at this site include 37-mm, 75-mm, 76-mm, 105-mm, and 155-mm projectiles. The analysts were provided information about the historical use and known munitions. In addition to these munitions, demonstrators were directed that any unexpected munitions would also be considered TOI.

The final demonstration site was seeded with enough TOI to ensure statistical validity on measures of classification of targets of interest. The TOI seeds are listed in Table 3-1. The seeds included not only inert projectiles, but also small and medium industry standard objects (ISOs). (Ref. 3) The ISOs are also considered TOI and expected to be both detected and correctly classified.

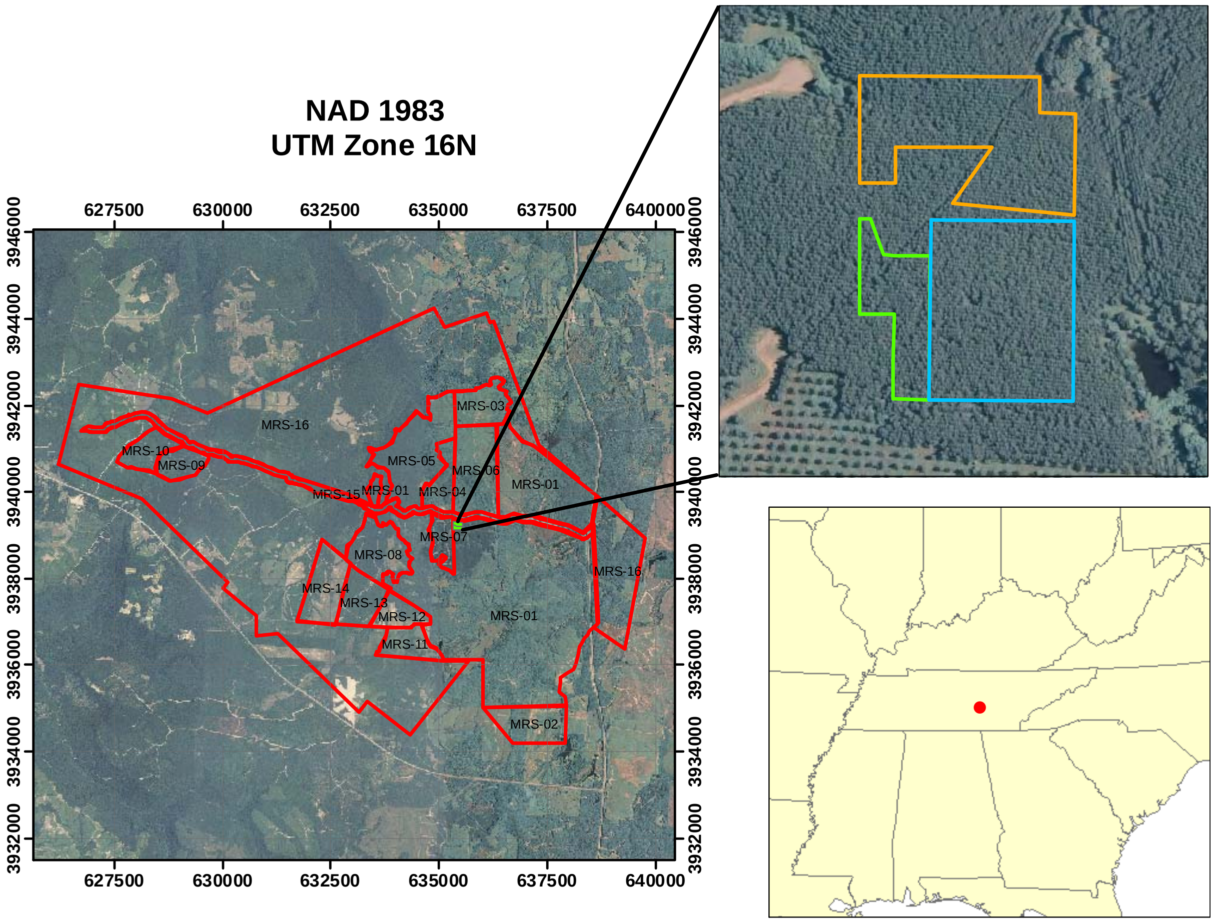

Figure 3-1. Aerial photo of the former Spencer Artillery Range showing the demonstration areas. The Open Area is outlined in blue, the Dynamic Area in green and the Wooded Area in orange. The Open and Dynamic Areas have been logged since the time of this photograph.

For safety, seeds were emplaced using standard anomaly avoidance procedures. No attempt was made to separate the seeds from the surrounding clutter. For realism, the emplacement teams were instructed to replace any metal dug up during emplacement back in the hole with the seeded object. To further test the analysts' ability to distinguish multiple objects in the field-of-view of the sensor, 18 of the seeds were emplaced with one or two fragments either 20 or 30 cm away.

Table 3-1. Seeds Emplaced in the Open Area at Spencer Range

Item	Number	Depth Range (cm)*
Small ISO80	28	15-30
37-mm projectile	28	15-30
Medium ISO40	5	15-45
60-mm mortar	5	15-45
75-mm projectile	14	15-46
105-mm projectile	1	45
155-mm projectile	1	45

*Depths are to the center of the object.

4. EM61 Detection Survey

An initial survey was performed with an EM61-MK2 in its standard cart configuration with cm-level global-positioning-system (GPS) navigation. These data were used to provide a common anomaly list for the two MetalMapper data collections that were to follow. No classification was attempted using these data as it has been shown previously that these data are not useful for classification. (Ref.6)

The data quality objectives for the detection survey were based on the 37-mm projectile, which was expected to be the most difficult to detect TOI at the site. The EM61 survey was performed on half-meter line spacing. The anomaly selection criteria were set to detect a 37-mm projectile at a depth of 34 cm. This depth was chosen as the deepest depth to which a 37-mm could be reliably detected. The EM61 signal strength in channel 2 versus depth for the 37-mm is shown in Figure 4-1. (Ref. 7) The signal at 34-cm depth for the least favorable orientation is 4.0 mV, which was used as the amplitude threshold for identifying anomalies.

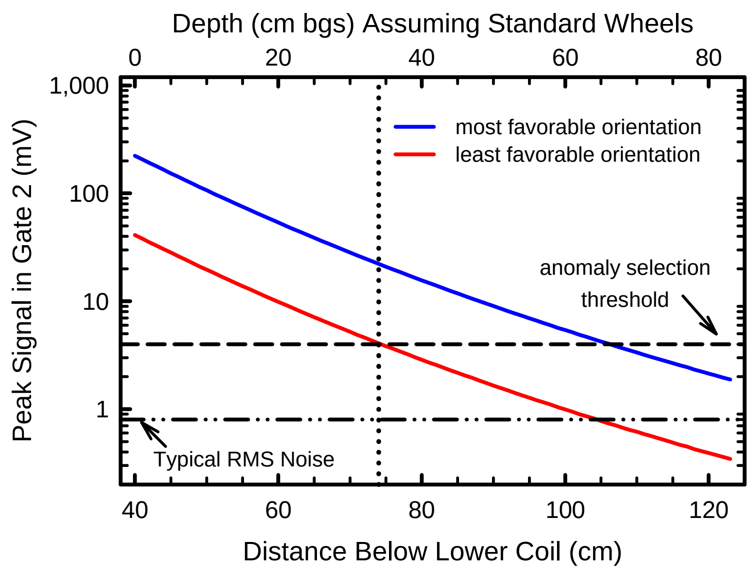

Figure 4-1. EM61 response in Gate 2 versus depth for a 37-mm projectile

The EM61 survey resulted in a total of 1104 anomalies in the 4.4-acre Open Area, including the seeds. This translates to approximately 250 anomalies per acre. Details can be found in the vendor's report. (Ref. 7) All seeds were detected in the EM61 survey.

5. MetalMapper and Data Collection

The MetalMapper developed by Geometrics is designed to be a stand-alone survey and cued detection system. The system, shown in Figure 5-1, is composed of three orthogonal 1-m x 1-m transmitters for target illumination and 7 three-axis receivers for recording the response. Its sampling is electronically programmable and therefore flexible. It measured the decay curve up to 8 ms after the transmitters were turned off. Centimeter-level GPS is used for navigation and geolocation and an inertial measurement unit (IMU) is used to measure platform orientation. In cued mode, MetalMapper is positioned over each anomaly on its target list and collects the full suite of data while stationary. The digital data set produced by MetalMapper is fully described in Ref. 4.

Figure 5-1. Schematic and photo of the MetalMapper as used at former Spencer Range

In this portion of the demonstration MetalMapper was used only in cued mode. It was deployed in a sled configuration mounted to the front of a tractor. Two commercial geophysics vendors, URS, Inc. and NAEVA, collected MetalMapper data at Spencer Range. Operators were trained in the field operations and QC procedures and data were initially QCed by personnel with prior experience with MetalMapper.

Details on the data collection and QC procedures followed by each vendor can be found in the respective reports. (Ref. 8, 9) The most common QC failure was that the MetalMapper was positioned too far from the anomaly to obtain reliable parameter estimates. If the separation between the center of the MetalMapper and the anomaly location was more than 40 cm, the anomaly was revisited and additional data collected within the 40-cm specification.

Both data sets were analyzed by multiple analysts. Although there were small differences in various measures of data quality, both data sets were of high overall quality and acceptable to perform classification. Detailed comparisons of the analyses of the two data sets can be found in the individual analysts' reports available on the SERDP-ESTCP web site (http://serdp-estcp.org/Featured-Initiatives/Munitions-Response-Initiatives/Classification-Applied-to-Munitions-Response/ Former-Spencer-Artillery-Range).

The production rates for the two data collectors were 214 and 228 targets per day for URS and NAEVA respectively. URS reported recollecting data on about 5% of the total anomalies due to QC failures, while NAEVA reported an overall rate of 14%. Both contractors noted that these rates reflect inefficiency inherent in learning to operate a new system and are not likely predictive of future productivity.

6. Intrusive Investigation

A summary of the results of the intrusive investigation is shown in Figure 6-1. The left panel in the figure shows the distribution of the number of items that were recovered from a single hole. As expected given the moderate anomaly density at this site (~250/acre), more than 85% of the anomalies were caused by a single buried item. The pie chart on the right hand side of Figure 6-1 shows the identities of the recovered objects. The majority of the recoveries (~90%) were identified as munitions debris; not unexpected for an impact area. Only ten items were identified as "other debris."

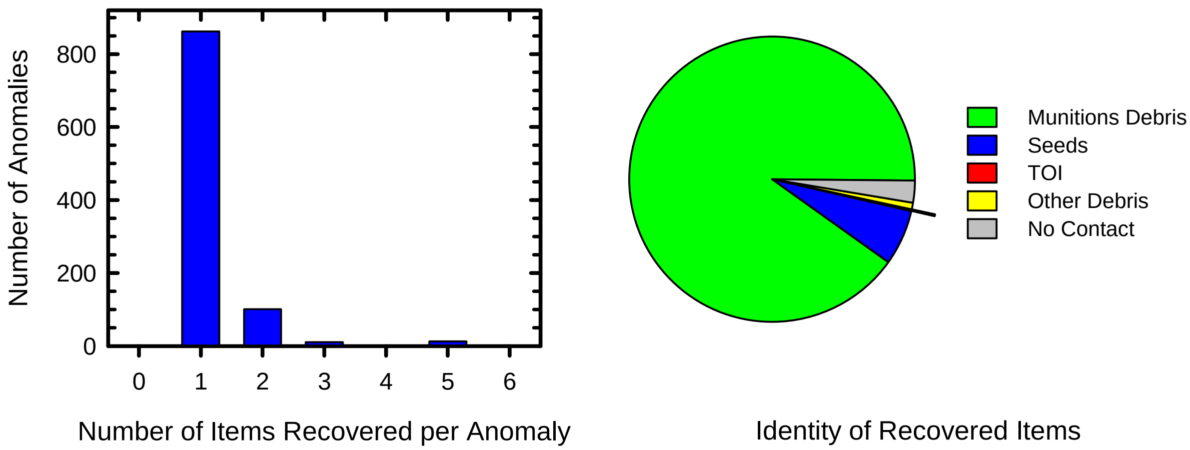

Figure 6-1. Distribution of items recovered per anomaly (left panel) and identity of recovered items (right panel)

Three non-seed TOI were recovered as part of this demonstration; none of the three required detonation by the UXO crew.

The depth distribution of the recovered items is given by the blue line in Figure 6-2. As at most munitions sites, the vast majority of items were recovered in the top 10 to 20 cm. The depths of the three recovered TOI are indicated by the stars and the depth range of the seeds by the grey bars.

As has been the case in all the ESTCP demonstrations to date, the seed items were buried deeper than the vast majority of items recovered from the site. One 75-mm projectile, however, was recovered at 64 cm which is below the depth range of the 75-mm seeds. Other than this item, the seeds proved to be a conservative QC test.

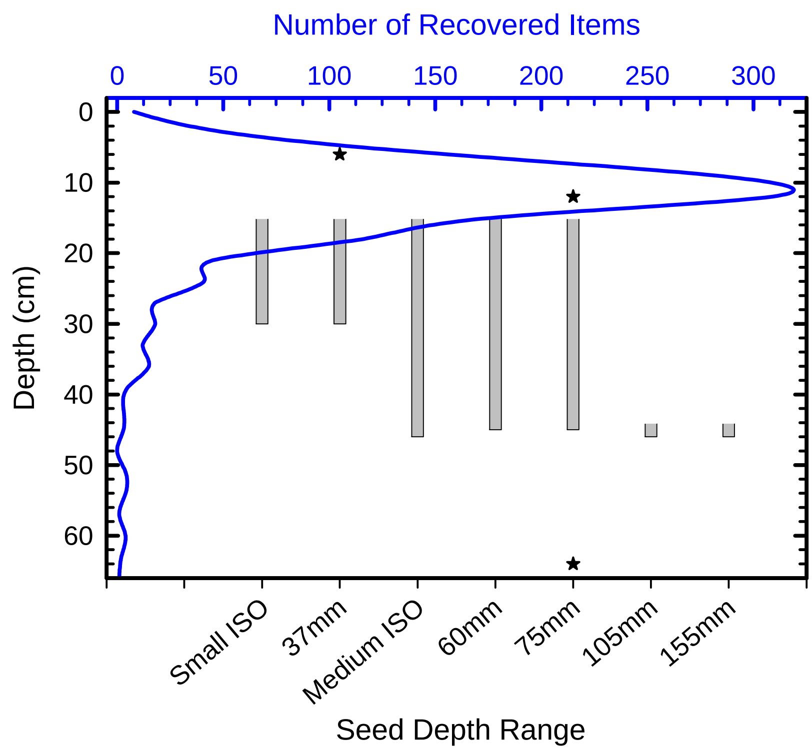

Figure 6-2. Depth distribution of recovered items from Spencer Range (blue line). The depths of the three TOI recovered in the Open Area are marked by stars and the depth range of the QC seeds are shown as grey bars.

7. Data Analysis

All data sets were analyzed by multiple analysts, including both the developers of the analysis methods and production geophysics vendors. Figure 7-1 shows an overview of the results achieved by all analysts working with the MetalMapper data. The panel on the left shows the percent of TOI correctly classified versus the number of clutter at each analyst's operating threshold. The inset expands the upper left of the graph for clarity. Desired performance is to correctly classify 100% of the TOI and eliminate all of the clutter. The panel on the right shows the number of clutter that the analyst needed to dig to get to 100% correct classification of the TOI, regardless of where the analyst put the threshold. This can be thought of as the best the analyst could have done by putting the threshold in exactly the optimum place where the last TOI is found in the ranked list. The symbols above the bars correspond to the symbols in the left panel.

At their specified thresholds, most analysts achieved good results, correctly classifying greater than 95% of the TOI and eliminating 70-90% of the clutter. This includes both the classification algorithm developers and the production contractors and is quite remarkable, especially considering that this was the first attempt at analyzing MetalMapper data by many of these analysts.

This range is even more evident in the right panel. The best performer could have eliminated all but 52 of the clutter (a 95% reduction) with 100% correct classification of TOI, where as the poorest performer at best could have eliminated about only 18% of the clutter.

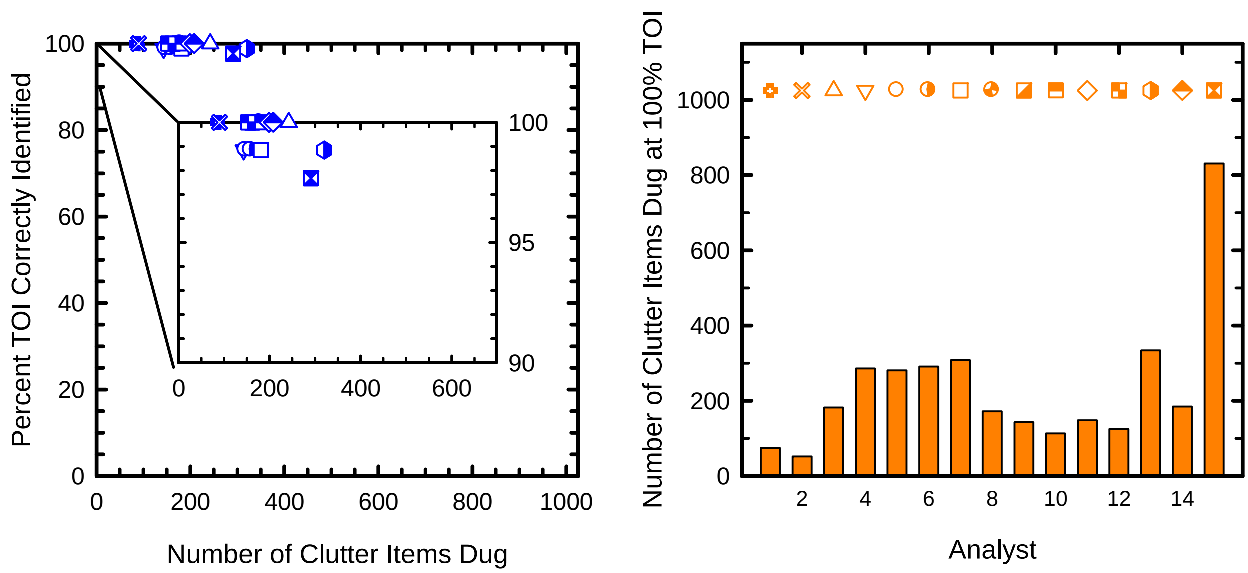

Figure 7-1. Results from all analysts in the Spencer Open Area demonstration. The left panel shows the percent TOI correctly identified versus number of clutter at the analysts chosen threshold. The right panel shows the number of clutter that would have to be dug to classify 100% of the TOI, regardless of where the analyst put the threshold.

7.1 Example Analysis Results

An analyst from Dartmouth College processed the cued MPV data using methods developed in house. (Ref. 0) The results of this analysis are shown in Figure 7-2. The colors on the plot correspond to the red and green colors in the final ranked anomaly list as shown in Figure 2-2. The red are the items the analyst classified as "high likelihood TOI" and the green are those the analyst called "high likelihood not TOI." No anomalies were classified as "unable to classify."

The graph plots the percent of the TOI correctly classified on the vertical axis and the number of clutter items on the horizontal axis. The offset from zero in the starting point reflects the training data that the analyst requested. Any anomalies classified as "can't extract reliable parameters" would be represented by an initial black line; no anomalies were in this category for this analysis. The blue dot represents the threshold selected by the analyst and the orange dot shows the point on the ranked anomaly list where 100% of the TOI are captured. Ideally, a classifier would correctly identify all targets of interest in the red with zero clutter and all of the clutter would be in the green. In this case, the red part of the curve would go straight up to 100% and the green part of the curve would run straight across the top axis. Success in these demonstrations was defined by eliminating the maximum amount of clutter while correctly identifying all of the TOI.

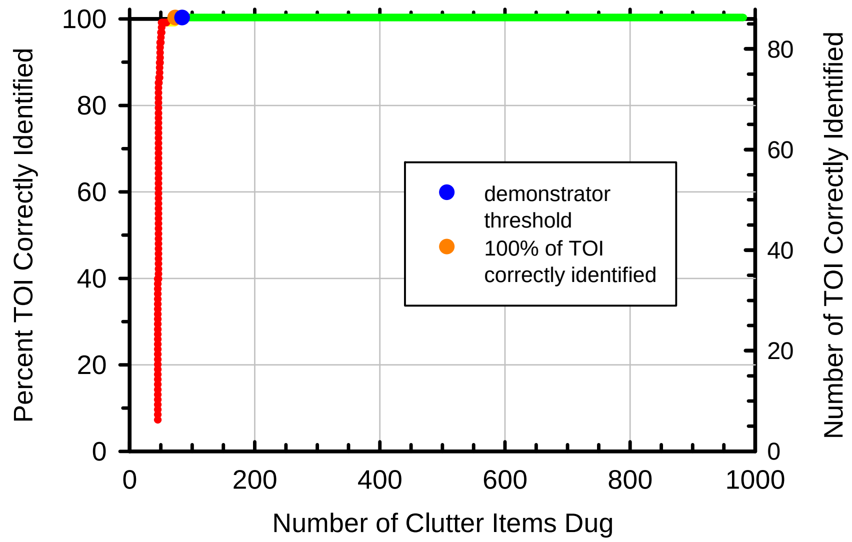

Figure 7-2. Results of a Dartmouth analysis of the MetalMapper data collected by NAEVA

In this demonstration, there were 983 total clutter items as determined from the ground truth. The Dartmouth analyst was able to correctly identify all but 85 of these items at her threshold, for a possible savings of more than 90% of the digs.

An analyst from the US Army Corps of Engineers also achieved good results using the NAEVA data, Figure 7-3. This analyst used very little site-specific training data (the ROC curve starts very near the origin) and was able to identify ~80% of the TOI very efficiently and identify 100% of the TOI while saving nearly 80% of the clutter digs. The difference between this analyst and the Dartmouth analyst is primarily experience with these techniques.

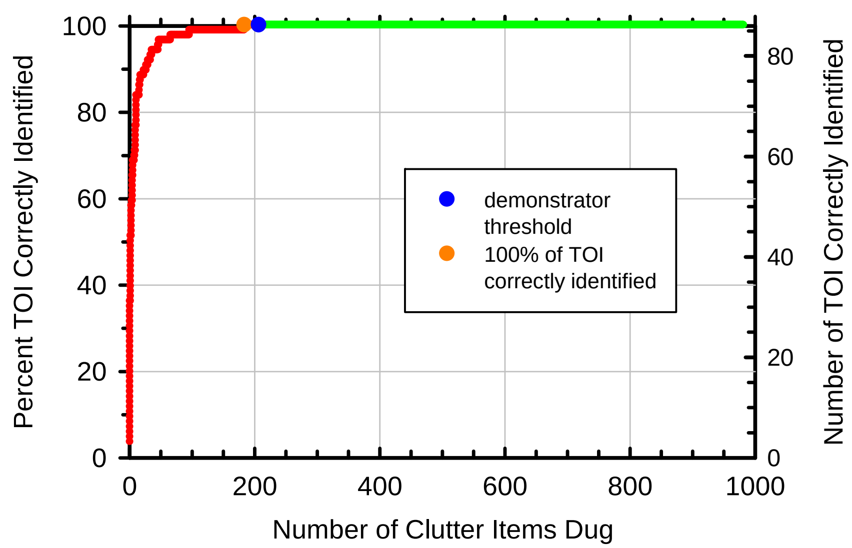

Figure 7-3. Results of the USACE analysis of the MetalMapper data collected by NAEVA

Similar results were obtained by a novice analyst from Shaw using the MetalMapper data collected by URS as seen in Figure 7-4. This analyst identified 70% of the TOI with high efficiency and 100% of the TOI while saving over 80% of the clutter digs.

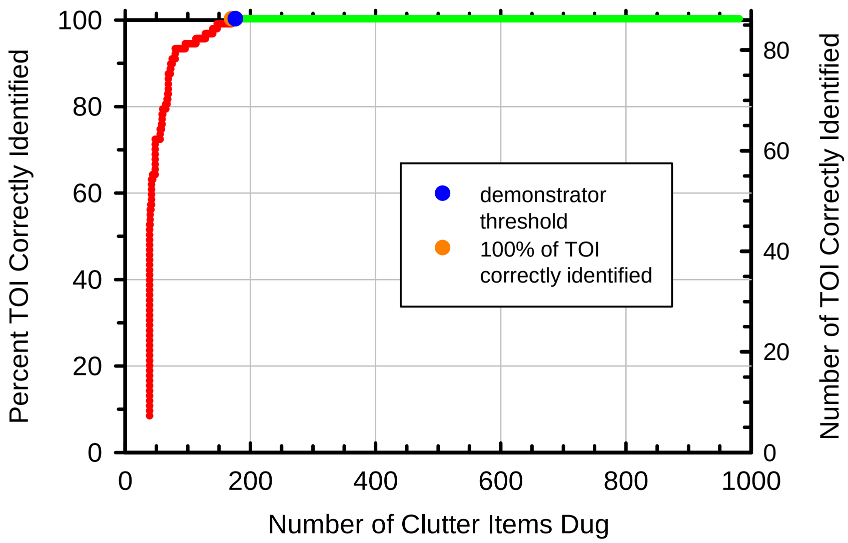

Figure 7-4. Results of the Shaw analysis of the MetalMapper data collected by URS

Not all analysts correctly identified 100% of the TOI at their threshold. The curve in Figure 7-5 is representative of a number of analyses. This analyst was very efficient at identifying all but one TOI. The missed TOI was a small ISO80 with a piece of frag almost directly above the seed. This is a case where an analyst with greater experience with the multi-source solvers that are beginning to become standard in the commercially-available analysis programs may have identified this seed item.

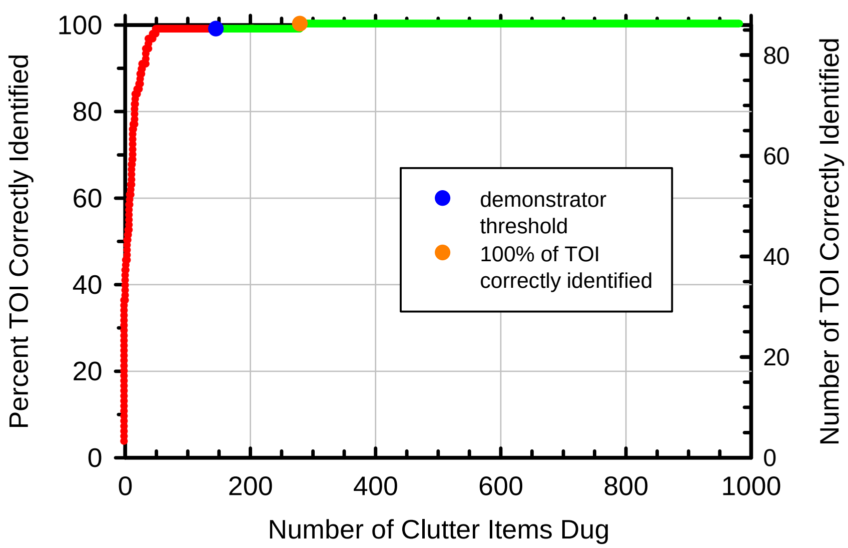

Figure 7-5. Results of the NAEVA analysis of the MetalMapper data collected by NAEVA

8. Cost Comparison

The demonstration took place on a small part of the former Spencer Artillery Range and incurred costs for many items specific to a demonstration that would not be needed in an application of classification to a real site. Nevertheless, we can extract meaningful projected performance for the technology and apply reasonable industry unit costs for various elements to arrive at a total cost comparison for clearing an example 100-acre site with and without the use of classification.

We made the following assumptions:

- The example takes place in an area with similar munitions types and the same density of anomalies as seen in this demonstration. There were approximately 250 anomalies per acre at the demonstration site. Extrapolating, we would expect about 25,000 anomalies in a similar 100-acre area, with 24,925 clutter.
- Mob/demob and a surface sweep would be required for either scenario.
- Three TOI were found during the intrusive investigation of the ~4-acre area. In a 100-acre site we predict about 75 native TOI.
- The baseline is an EM61 survey with 0.5-m line spacing. This would be used to select anomalies for digging without classification and for cueing with the advanced sensor in hybrid mode.
- Survey data will be collected using MetalMapper in dynamic mode for the advanced sensor only mode.
- The site is seeded at a rate so on average one seed will be encountered each day of MetalMapper data collection. With an estimate of 25,000 total anomalies and a production rate of 200 anomalies per day, we seed 125 inert items. These QC seeds would be used whether classification was used on the site or not.
- The classification performance is as achieved by the production firms with ~80% of the clutter correctly identified and remaining undug.
- The unit costs are as shown in Table 8-1.

Table 8-1. Unit cost assumptions

Item	Units	Cost
Mob/Demob	1	$7,000
Surface Sweep	acre	$2,500
IVS and Seed Emplacement	125 seeds	$22,650
EM61 Survey Data Collection and Analysis	acre	$1,000
Dynamic MetalMapper Data Collection and Analysis	acre	$5,000
Cued MetalMapper Data Collection and Analysis	per anomaly	$30
Digs	per dig	$125

With these assumptions the costs were calculated using the elements shown in Table 8-2. Using a hybrid approach in which anomalies are identified from an EM61-MK2 survey and cued data is collected with the MetalMapper (the method used in this demonstration), a 49% savings on project field work can be realized.

As the Classification demonstration program has progressed, it has become apparent that a significant number of anomalies can be classified using data collected dynamically using advanced EMI sensors. This raises the possibility of performing the anomaly detection step using advanced sensors, classifying many of the anomalies using the same data set (2/3 of the anomalies in a recent test), and only having to collect cued data over a subset of the anomalies. The cost estimate for this "Advanced Sensor Only" mode is given in the rightmost two columns in Table 8-2.

Given the reduced number of data collections, one might expect the savings from the advanced sensor only mode to be much greater than the hybrid approach. The current generation of advanced sensors are not configured to be deployed in arrays so the cost for the advanced sensor detection survey at this example site is much higher than for detection using an EM61-MK2 array. As the operation of these advanced sensors in dynamic mode is explored further, it is possible that this cost disadvantage will lessen.

Table 8-2. Cost Comparison for 100 acres of comparable Spencer Range site

	No Classification		Hybrid Approach[1]		Advanced Sensor Only[2]	
Work Item	**Quantity**	**Cost/$**	**Quantity**	**Cost/$**	**Quantity**	**Cost/$**
Mob/demob	1	7,000	1	7,000	1	7,000
Surface Sweep	100 acres	250,000	100 acres	250,000	100 acres	250,000
Seeds	125 items	22,650	125 items	22,650	125 items	22,650
EM61 Survey	100 acres	100,000	100 acres	100,000	n/a	
MetalMapper Survey	n/a		n/a		100 acres	500,000
Cued MetalMapper	n/a		25,000 anomalies	750,000	8,333 anomalies	249,990
Seeds Dug	125	15,625	125	15,625	125	15,625
Native UXO Dug	75	9,375	75	9,375	75	9,375
Clutter Dug	24,925	3,115,625	4,985	623,125	4,985	623,125
TOTAL		3,520,275		1,777,775		1,677,765
Percent Savings				**49%**		**52%**

[1] Hybrid approach denotes the method used in this demonstration, anomaly detection from an EM61-MK2 survey with cued data collection using advanced sensors.

[2] Advanced sensor only approach refers to anomaly detection and classification of 2/3 of the anomalies using MetalMapper in dynamic mode and cued data collection on the remaining 1/3 of the anomalies.

9. Conclusions

Production contractor field crews from two different vendors collected high quality cued MetalMapper data used on the former Spencer Artillery Range Open Area. Both production contractor geophysicists and the developers of classification methods were successful in using these data to achieve substantial classification. Most analysts correctly identified all, or all but one, TOI while correctly classifying 75 to 90% of the clutter.

The best predictor of classification performance was analyst experience. Figure 9-1 repeats the left panel of Figure 7-1 with the points colored to denote the experience of the analyst. While not all novice analysts were at the lower end of the performance metric and not all experienced analysts achieved perfect classification, the results are generally reflective of the analyst's experience. This points to continued analyst training as an important component of technology transfer for these technologies.

As can be seen in Figure 9-1, one of the experienced analysts did not correctly classify one of the TOI, an inert 37-mm QC seed. This illustrates the importance of a well-defined and executed QC program.

The Spencer Range site is an excellent site for classification using advanced EMI sensors. The flat terrain and corresponding low survey noise led to excellent detection and classification results.

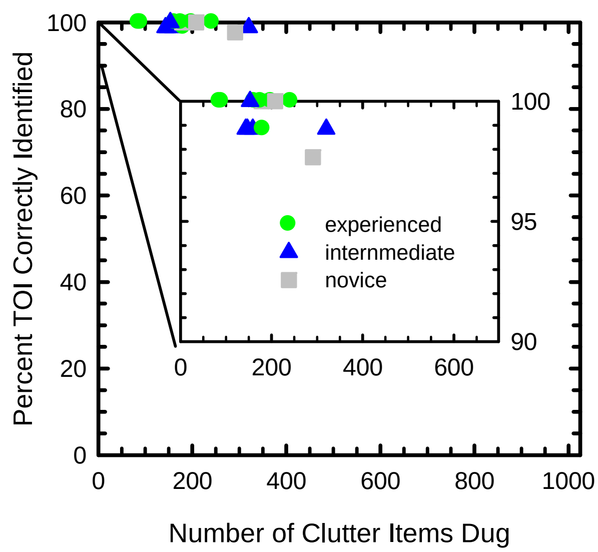

Figure 9-1. Plot from the left panel of Figure 7-1 with the points colored by analyst experience

10. Acronyms

BRAC	Base Realignment and Closure
CO	Colorado
EM	Electromagnetic
EMI	Electromagnetic Induction
ESTCP	Environmental Security Technology Certification Program
FUDS	Formerly Used Defense Site
GPS	Global Positioning System
IMU	Inertial Measurement Unit
ISO	Industry Standard Object

IVS	Instrument Verification Strip
MPV	Man-portable Vector [Sensor]
QC	Quality Control
SERDP	Strategic Environmental Research and Development Program
TOI	Target of Interest
UXO	Unexploded Ordnance

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